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An effect of turbulence on the stability of a zonal flow on a beta plane

Kiori Obuse[1*], Shin-ichi Takehiro[1], Michio Yamada[1]

[1]RIMS, Kyoto University

Forced two-dimensional barotropic incompressible flows on a sphere is sometimes used as a simple model for large-scale flows on a planet, because of the rotation effect of the planet and the effect of the stratification of the fluid. It has been well known that, in this model, a multiple zonal-band structure which is a structure with many alternating eastward and westward jets, emerges in the course of time development, and lasts for quite a long time (Nozawa and Yoden 1997, Huang and Robinson 1998). The persistence of the structure is often explained in terms of the Rhines wavenumber at which the rotation effect and the advective effect become comparable (Rhines 1975).

However, recent numerical experiments show that when the time integration is carried much further than in the previous studies, the multiple zonal jets experience gradual mergers/disappearances, and then a structure with two or three alternating large zonal jets is realised asymptotically (Huang et al. 2001, Obuse et al. 2009). There, the representative wavenumber of the flow intermittently decreases, passing though the Rhines wavenumber, and finally reaches much lower value than the Rhines wavenumber. One of the interpretations that simply expected for such mergers/disappearances of zonal jets might be the instability of laminar zonal jets. The laminar zonal jets having the wavenumber lower than the Rhines wavenumber, however, are always linearly stable, because they always satisfy the Rayleigh's sufficient condition for stability. Hence, the turbulence behind the zonal jets seems to play an important role in mergers/disappearances of the zonal jets.

To investigate the effect of the turbulence, we considered zonal jets having a transverse sinusoidal background flow modeled on the turbulence. This model was originally introduced and numerically investigated in Manfroi and Young (1999). The numerical experiment they performed showed that a structure with many zonal jets appears from a random initial condition, then its zonal jets slowly disappear one by one, resulting only one jet in the considered domain.

We then derived an analytical stationary solution of the governing equation of the zonal jets that Manfroi and Young(1999) derived, and analytically and numerically investigated its linear stability. The domain that realises such jets has determined in a parameter space, and all the jets there were revealed to be linearly unstable. Then the final state of the perturbed unstable steady jet was numerically confirmed to be a uniform flow, which is consistent with the disappearances of the jets occurring in the numerical experiment in Manfroi and Young (1999). These results may suggest that above-mentioned merger/disappearance of the zonal jets in the forced two-dimensional barotropic model on a rotating sphere is due to the intrinsic instability of the zonal jets, and that the effect of the turbulence behind the jets is essential for it.

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